Z' bosons from E_6: collider and electroweak constraints

Jens Erler (IF-UNAM)

DIS 2011

Newport News Marriott at City Center
Newport News, VA, USA April 13, 2011

Outline

Outline

- why care about Z' bosons?

Outline

- why care about Z' bosons?
- Z' bosons from E_6

Outline

- why care about Z' bosons?
- Z' bosons from E_6
- Z' constraints from electroweak precision data

Outline

- why care about Z' bosons?
- Z' bosons from E_6
- Z' constraints from electroweak precision data
- Z' physics at hadron colliders

2

Outline

- why care about Z' bosons?
- Z' bosons from E_6
- Z' constraints from electroweak precision data
- Z' physics at hadron colliders
- towards an integrated Z' analysis

2

Outline

- why care about Z' bosons?
- Z' bosons from E_6
- Z' constraints from electroweak precision data
- Z' physics at hadron colliders
- towards an integrated Z' analysis
- based on work in collaboration with
  Paul Langacker, Shoaib Munir and Eduardo Rojas

2

why care about Z' bosons?

why care about Z' bosons?

- top-down: strings and GUTs

why care about Z' bosons?

- top-down: strings and GUTs
- bottom-up: models of dynamical symmetry breaking, SUSY, large/warped extra dimensions, little Higgs, …

on life support → U(1)′s as paramedics ⇒ $M_{Z'} = \mathcal{O}(\text{TeV})$

why care about Z' bosons?

- top-down: strings and GUTs
- bottom-up: models of dynamical symmetry breaking, SUSY, large/warped extra dimensions, little Higgs, …

  on life support → $U(1)'$s as paramedics ⇒ $M_{Z'} = \mathcal{O}(\text{TeV})$
- discovery: s-channel resonances at colliders, interference with γ/Z at low energies

3

why care about Z' bosons?

- top-down: strings and GUTs
- bottom-up: models of dynamical symmetry breaking, SUSY, large/warped extra dimensions, little Higgs, …
  on life support → $U(1)'$s as paramedics ⇒ $M_{Z'} = \mathcal{O}(\text{TeV})$
- discovery: s-channel resonances at colliders, interference with γ/Z at low energies
- discrimination: angular distribution can indicate spin

3

why care about Z' bosons?

- top-down: strings and GUTs
- bottom-up: models of dynamical symmetry breaking, SUSY, large/warped extra dimensions, little Higgs, …

  on life support → $U(1)'$s as paramedics ⇒ $M_{Z'} = \mathcal{O}(\text{TeV})$
- discovery: s-channel resonances at colliders, interference with γ/Z at low energies
- discrimination: angular distribution can indicate spin
- diagnostics: charges can hint at underlying principles

3

Z' bosons from E_6

Z' bosons from E_6

- $Z' = \cos\alpha \cos\beta Z_\chi + \sin\alpha \cos\beta Z_Y + \sin\beta Z_\psi$

  $\sim c_1 Z_R + \sqrt{3} (c_2 Z_{R1} + c_3 Z_{L1})$

Z' bosons from E_6

- $Z' = \cos\alpha \cos\beta Z_\chi + \sin\alpha \cos\beta Z_Y + \sin\beta Z_\psi$

  $\sim c_1 Z_R + \sqrt{3} (c_2 Z_{R1} + c_3 Z_{L1})$

- kinetic mixing: $\alpha \neq 0 \sim F^{\mu\nu} F'_{\mu\nu}$

Z' bosons from E_6

- $Z' = \cos\alpha \cos\beta Z_\chi + \sin\alpha \cos\beta Z_Y + \sin\beta Z_\psi$

  $\sim c_1 Z_R + \sqrt{3}\,(c_2 Z_{R1} + c_3 Z_{L1})$

- kinetic mixing: $\alpha \neq 0 \sim F^{\mu\nu} F'_{\mu\nu}$

- $E_6 \rightarrow SO(10)\times U(1)_\psi \rightarrow SU(5)\times U(1)_\chi \times U(1)_\psi$

4

Z' bosons from E_6

- $Z' = \cos\alpha \cos\beta Z_\chi + \sin\alpha \cos\beta Z_Y + \sin\beta Z_\psi$

  $\sim c_1 Z_R + \sqrt{3}\,(c_2 Z_{R1} + c_3 Z_{L1})$

- kinetic mixing: $\alpha \neq 0 \sim F^{\mu\nu} F'_{\mu\nu}$

- $E_6 \rightarrow SO(10)\times U(1)_\psi \rightarrow SU(5)\times U(1)_\chi \times U(1)_\psi$

- trinification: $E_6 \rightarrow SU(3)^3 \rightarrow$
  $SU(3)_C \times SU(2)_L \times U(1)_{L1} \times SU(2)_R \times U(1)_{R1}$

4

Z' bosons from E_6

- $Z' = \cos\alpha \cos\beta Z_\chi + \sin\alpha \cos\beta Z_Y + \sin\beta Z_\psi$

  $\sim c_1 Z_R + \sqrt{3}\,(c_2 Z_{R1} + c_3 Z_{L1})$

- kinetic mixing: $\alpha \neq 0 \sim F^{\mu\nu} F'_{\mu\nu}$

- $E_6 \rightarrow SO(10)\times U(1)_\psi \rightarrow SU(5)\times U(1)_\chi \times U(1)_\psi$

- trinification: $E_6 \rightarrow SU(3)^3 \rightarrow$
  $SU(3)_C \times SU(2)_L \times U(1)_{L1} \times SU(2)_R \times U(1)_{R1}$

- classification in progress ***JE, E. Rojas, 2011***

4

Z' charges in E_6 models

l	ν		$-2c_2$	$-c_3$	$\overline{\nu}$	$-c_1$	$+c_2$	$+2c_3$
	e^-				e^+	$+c_1$	$+c_2$	$+2c_3$
q	u			$+c_3$	$\overline{u}$	$-c_1$	$-c_2$	
	d				$\overline{d}$	$+c_1$	$-c_2$	
L	N	$-c_1$	$+c_2$	$-c_3$	D			$-2c_3$
	E^-				$\overline{D}$		$+2c_2$	
$\overline{L}$	E^+	$+c_1$	$+c_2$	$-c_3$	S		$-2c_2$	$+2c_3$
	$\overline{N}$							

E_6 model class and SUSY

6

E_6 model class and SUSY

in SUSY when demanding ***JE, Nucl. Phys. B586, 73 (2000)***

E_6 model class and SUSY

in SUSY when demanding ***JE, Nucl. Phys. B586, 73 (2000)***

- SM Yukawa couplings allowed

E_6 model class and SUSY

in SUSY when demanding ***JE, Nucl. Phys. B586, 73 (2000)***

- SM Yukawa couplings allowed
- the U(1)′ provides a solution to the μ-problem

E_6 model class and SUSY

in SUSY when demanding ***JE, Nucl. Phys. B586, 73 (2000)***

- SM Yukawa couplings allowed
- the U(1)′ provides a solution to the μ-problem
- chirality & SUSY protect all fields against large masses

6

E_6 model class and SUSY

in SUSY when demanding ***JE, Nucl. Phys. B586, 73 (2000)***

- SM Yukawa couplings allowed
- the U(1)′ provides a solution to the μ-problem
- chirality & SUSY protect all fields against large masses
- gauge and gravitational anomaly cancellation

6

E_6 model class and SUSY

in SUSY when demanding ***JE, Nucl. Phys. B586, 73 (2000)***

- SM Yukawa couplings allowed
- the U(1)′ provides a solution to the μ-problem
- chirality & SUSY protect all fields against large masses
- gauge and gravitational anomaly cancellation
- gauge coupling unification

6

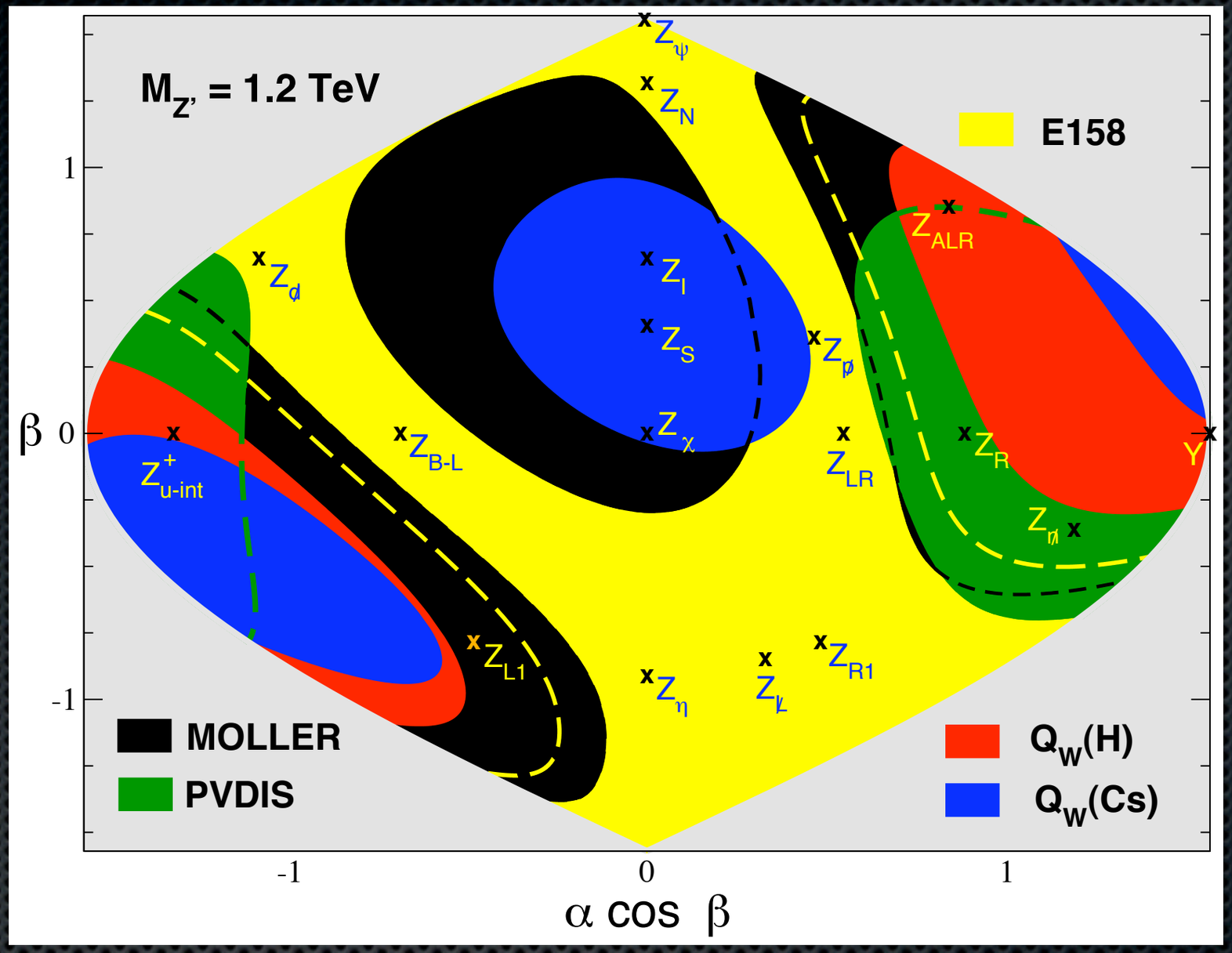
E_6 model class and SUSY

in SUSY when demanding ***JE, Nucl. Phys. B586, 73 (2000)***

- SM Yukawa couplings allowed
- the U(1)′ provides a solution to the μ-problem
- chirality & SUSY protect all fields against large masses
- gauge and gravitational anomaly cancellation
- gauge coupling unification

➡ the U(1)′ forbids dimension 4 proton decay

6



E_6 models & parity violation

E158, MOLLER, Qweak, SOLID, APV

7

Z' constraints from electroweak precision data

8

Z' constraints from electroweak precision data

- strongly constrain vector and axial-vector Z couplings

8

Z' constraints from electroweak precision data

- strongly constrain vector and axial-vector Z couplings
- $\Rightarrow \theta_{ZZ'} \lesssim \mathcal{O}(10^{-2})$

8

Z' constraints from electroweak precision data

- strongly constrain vector and axial-vector Z couplings
- $\Rightarrow \theta_{ZZ'} \lesssim \mathcal{O}(10^{-2})$
- $M_{Z'}$ bounds scale like $g'/M_{Z'}$

8

Z' constraints from electroweak precision data

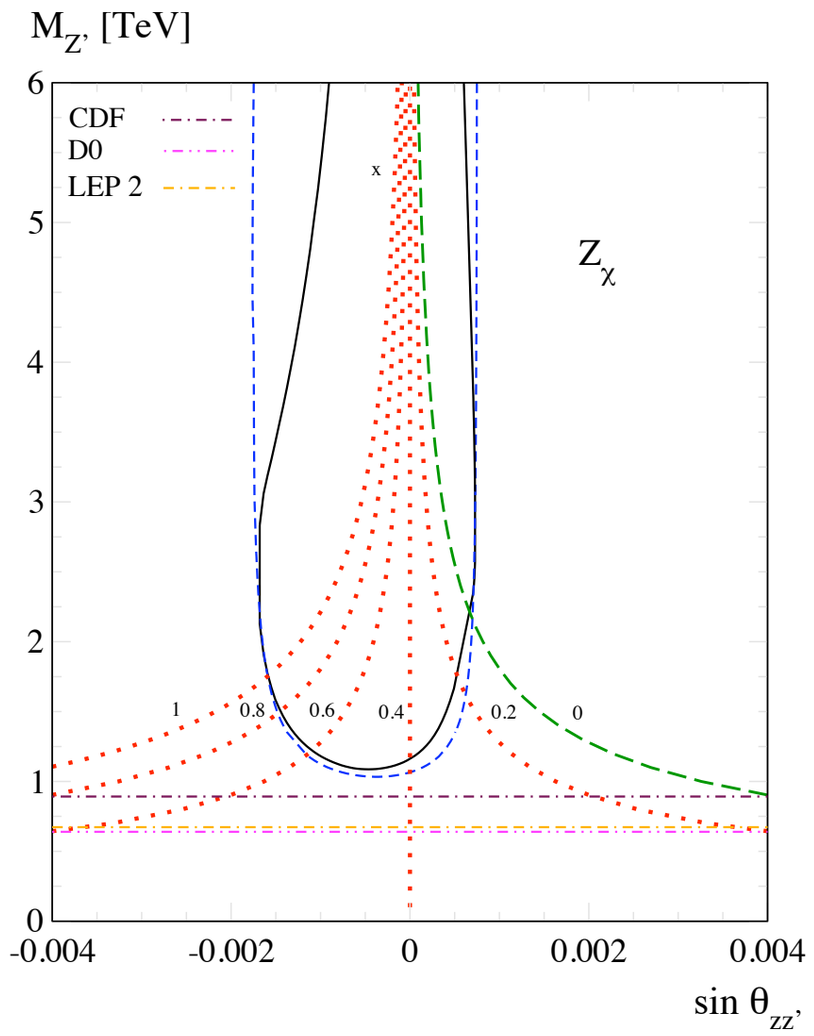
- strongly constrain vector and axial-vector Z couplings
- $\Rightarrow \theta_{ZZ'} \lesssim \mathcal{O}(10^{-2})$
- $M_{Z'}$ bounds scale like $g'/M_{Z'}$
- simultaneously constrain $U(1)'$ breaking Higgs sector

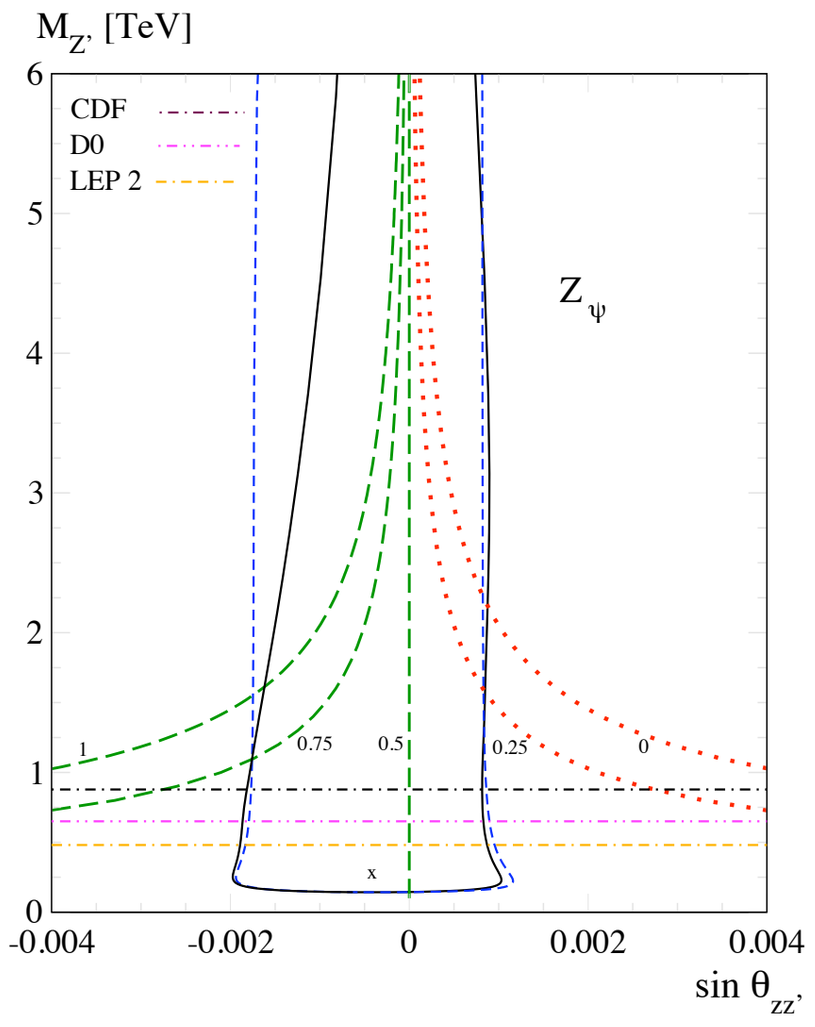
8

Z' constraints from electroweak precision data

- strongly constrain vector and axial-vector Z couplings
- $\Rightarrow \theta_{ZZ'} \lesssim \mathcal{O}(10^{-2})$
- $M_{Z'}$ bounds scale like $g'/M_{Z'}$
- simultaneously constrain U(1)′ breaking Higgs sector
- often raises preferred fit range of M_H relative to SM (cf. NMSSM) ***JE, P. Langacker, S. Munir, E. Rojas, JHEP 0908, 017 (2009)***

8





Global electroweak fit

Z lineshape, heavy flavor, Z pole asymmetries, m_t, M_W, ν-DIS, APV, polarized electron scattering

9

Z' physics at hadron colliders

10

Z' physics at hadron colliders

- $p\bar{p}$, pp: resonant production of e^+e^-, $\mu^+\mu^-$, $b\bar{b}$, $t\bar{t}$, dijets, associate production, FB-asymmetries

10

Z' physics at hadron colliders

- $p\bar{p}$, pp: resonant production of e^+e^-, $\mu^+\mu^-$, $b\bar{b}$, $t\bar{t}$, dijets, associate production, FB-asymmetries
- mild dependence of results on PDF set

JE, P. Langacker, S. Munir, E. Rojas, arXiv: 1103.2659 [hep-ph]

10

Z' physics at hadron colliders

- $p\bar{p}$, pp: resonant production of e^+e^-, $\mu^+\mu^-$, $b\bar{b}$, $t\bar{t}$, dijets, associate production, FB-asymmetries
- mild dependence of results on PDF set

JE, P. Langacker, S. Munir, E. Rojas, arXiv: 1103.2659 [hep-ph]

- mass dependent acceptance taken as Beta distribution

10

Z' physics at hadron colliders

- $p\bar{p}$, pp: resonant production of e^+e^-, $\mu^+\mu^-$, $b\bar{b}$, $t\bar{t}$, dijets, associate production, FB-asymmetries
- mild dependence of results on PDF set

JE, P. Langacker, S. Munir, E. Rojas, arXiv: 1103.2659 [hep-ph]

- mass dependent acceptance taken as Beta distribution
- QED and QCD corrections sizable

10

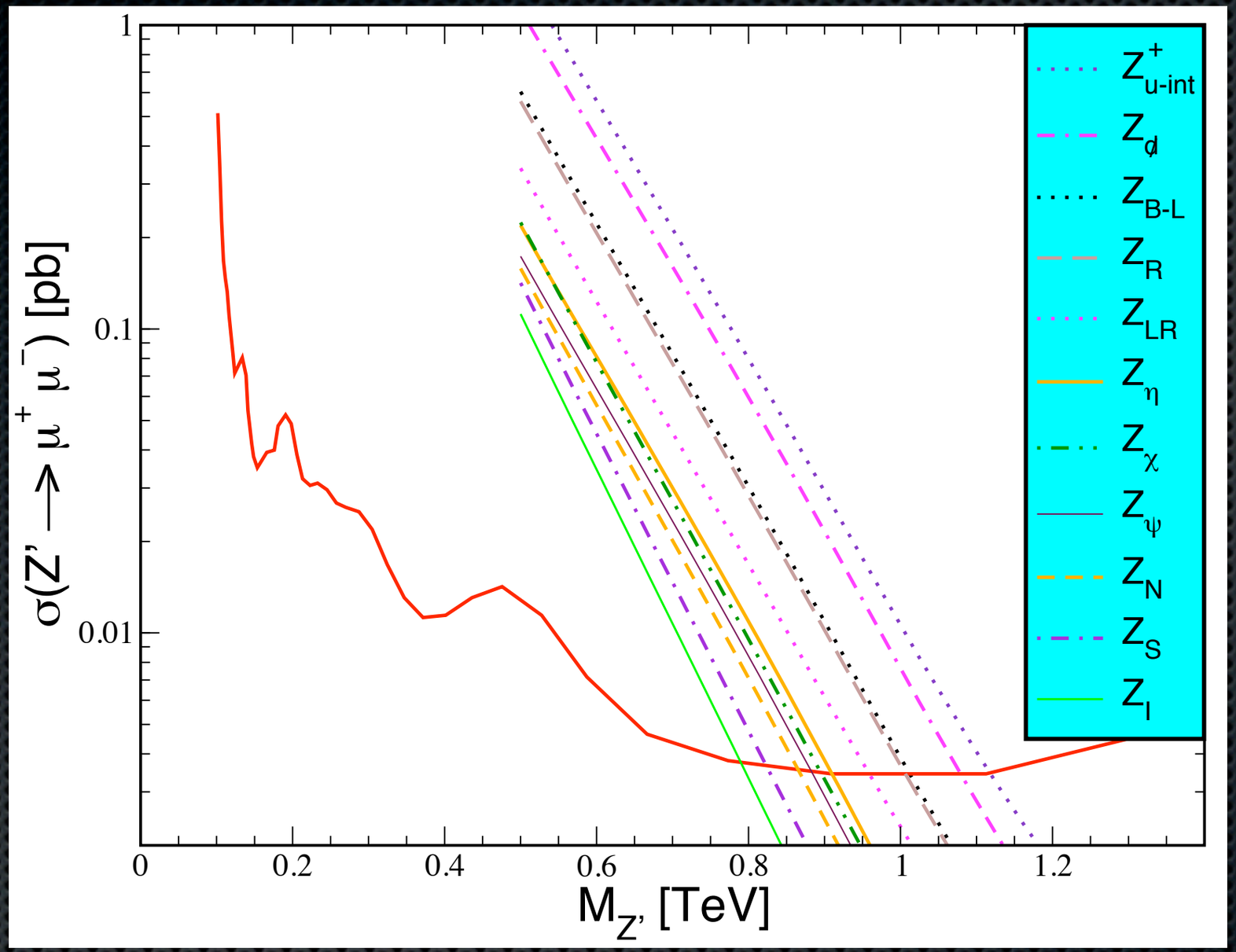
Z' physics at hadron colliders

- $p\bar{p}$, pp: resonant production of e^+e^-, $\mu^+\mu^-$, $b\bar{b}$, $t\bar{t}$, dijets, associate production, FB-asymmetries
- mild dependence of results on PDF set

JE, P. Langacker, S. Munir, E. Rojas, arXiv: 1103.2659 [hep-ph]

- mass dependent acceptance taken as Beta distribution
- QED and QCD corrections sizable
- systematic uncertainties currently neglegted

10

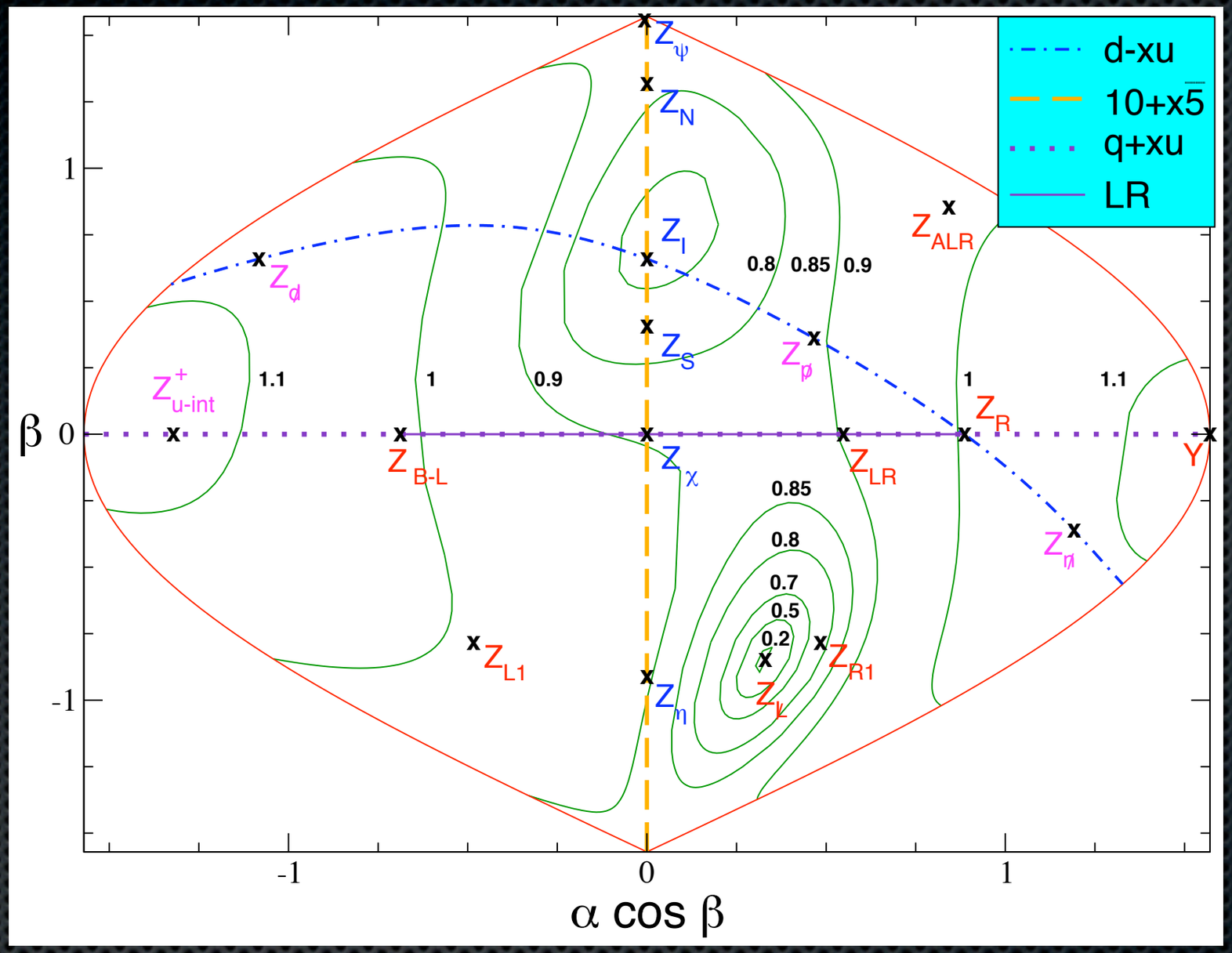


CDF style analysis

Good agreement with CDF model lines.

Several additional models included.

11

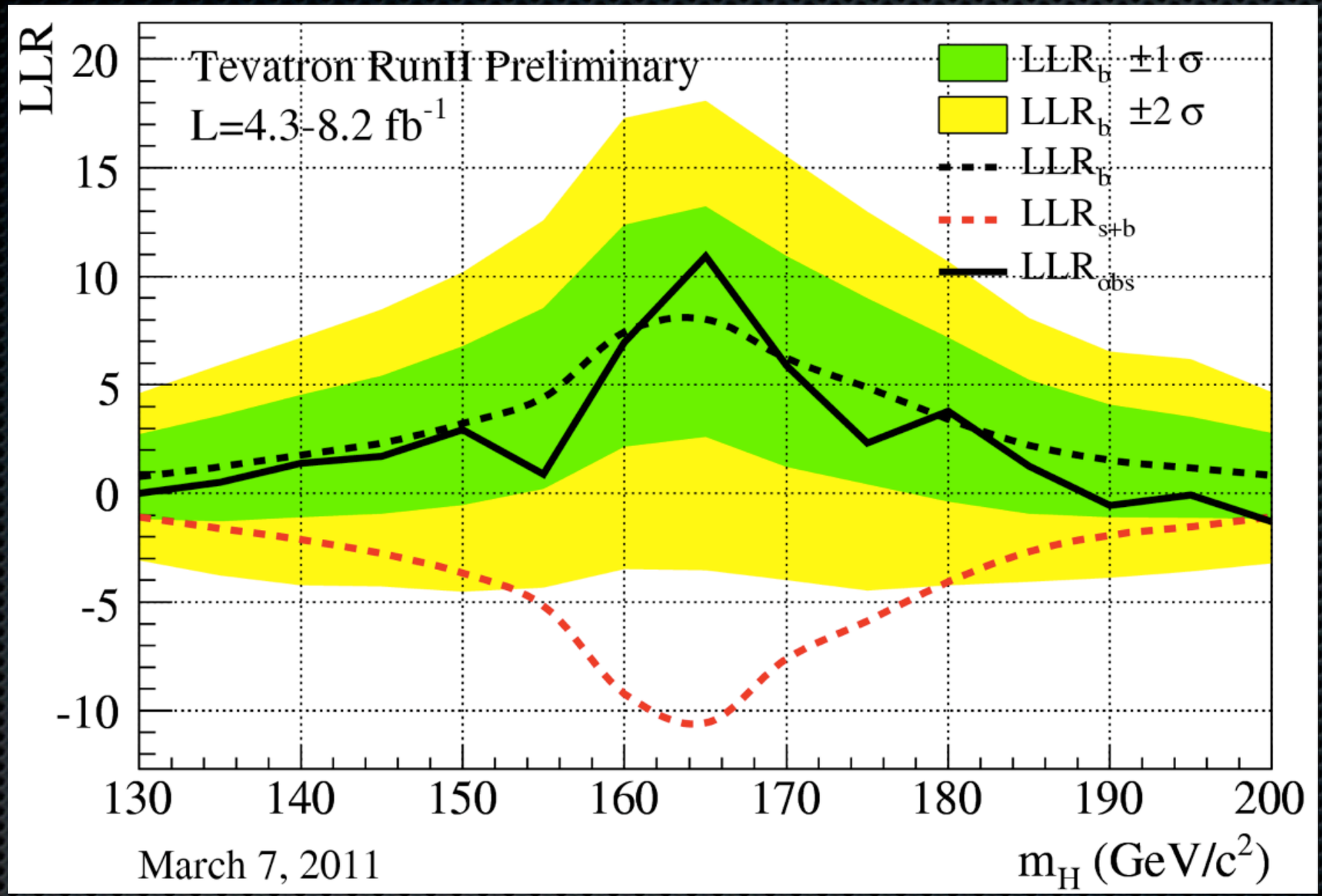


E_6 inspired models

horizontal line: SO(10) (including left-right) models

vertical line: no kinetic mixing; blue line: $U(1)_{d\text{-}xu}$

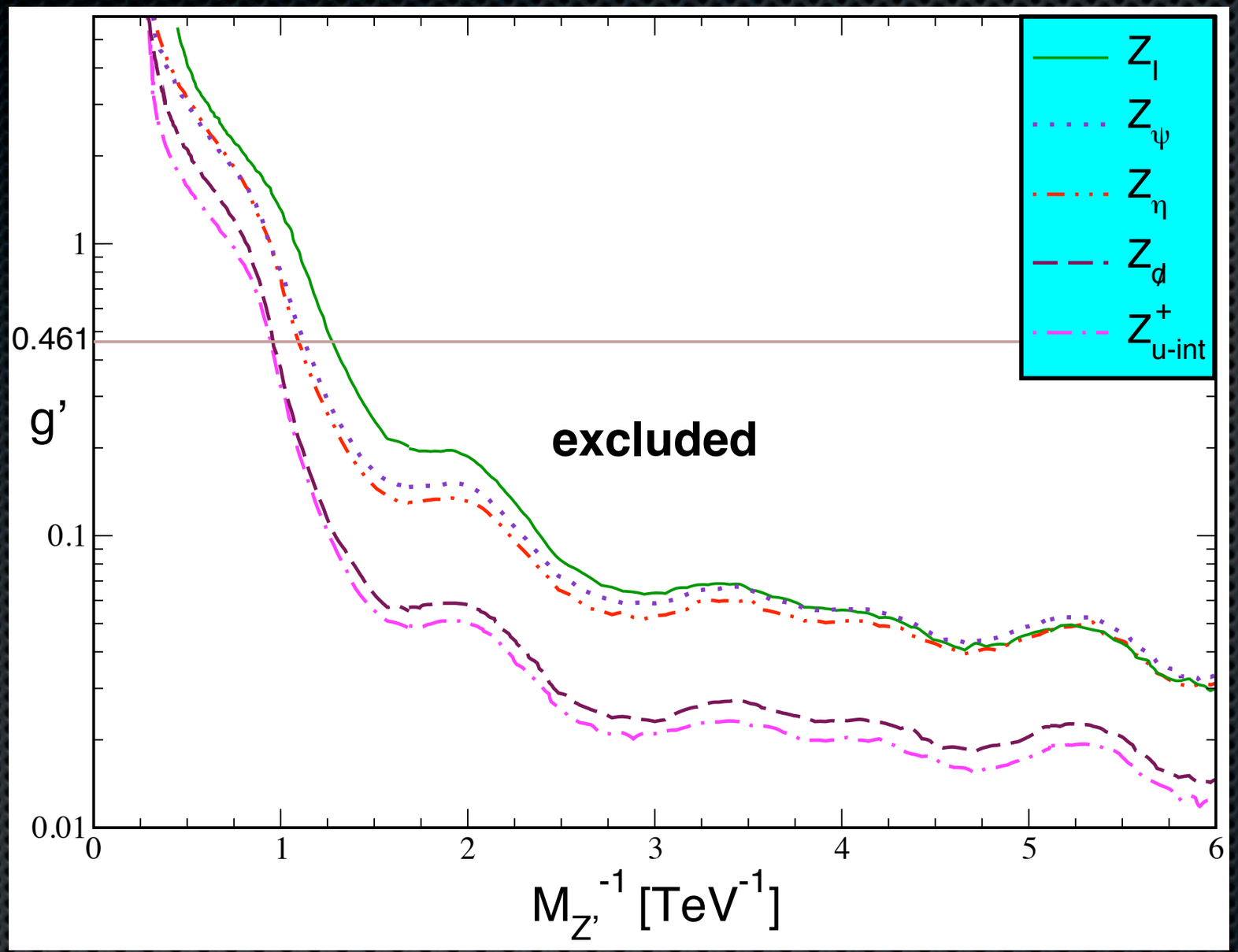
12



example LLR

Higgs boson search at the Tevatron

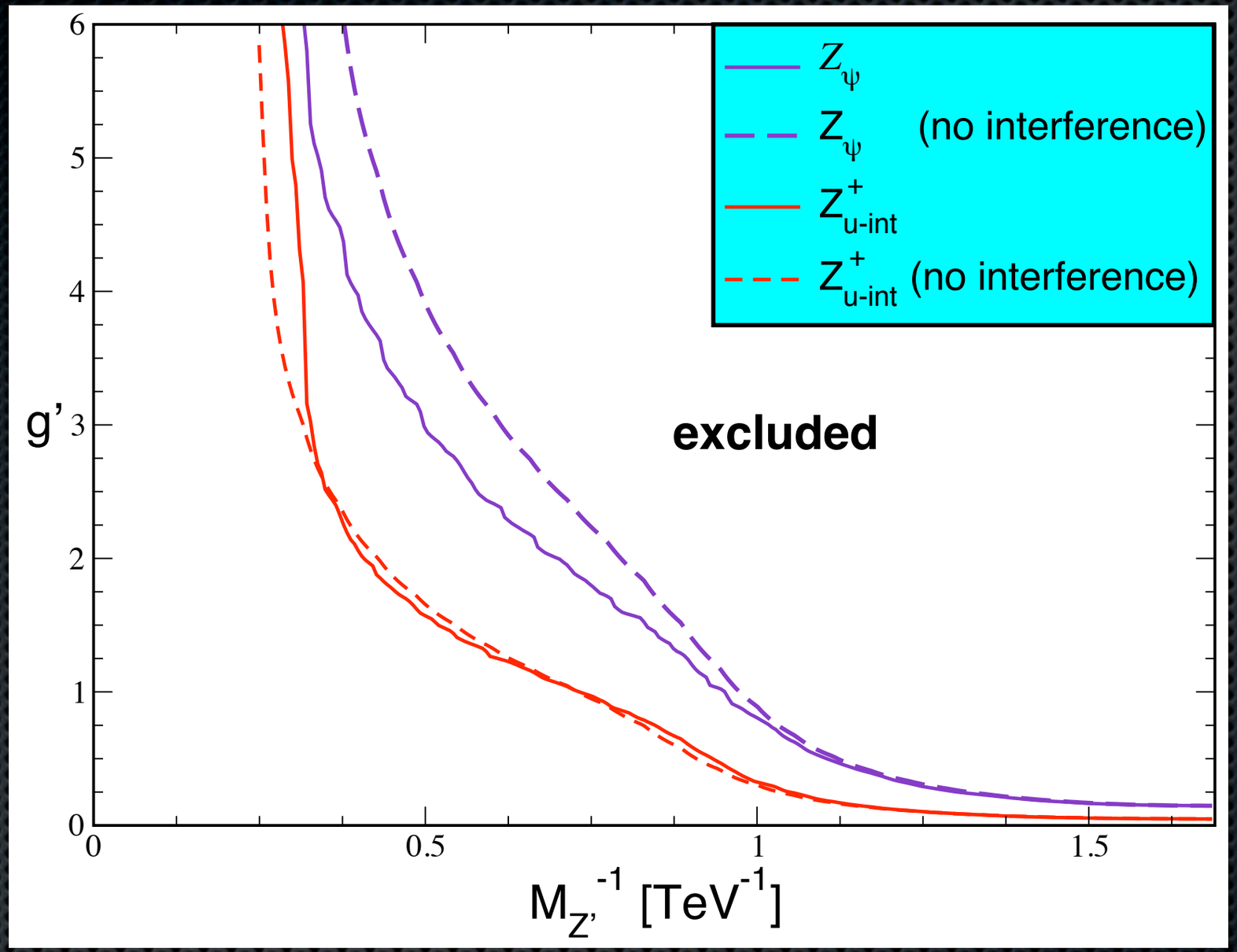
13



Bayesian style analysis

$\Delta\chi^2 = -2 \ln p(\text{data}|s+b)/p(\text{data}|b) < 5.99$

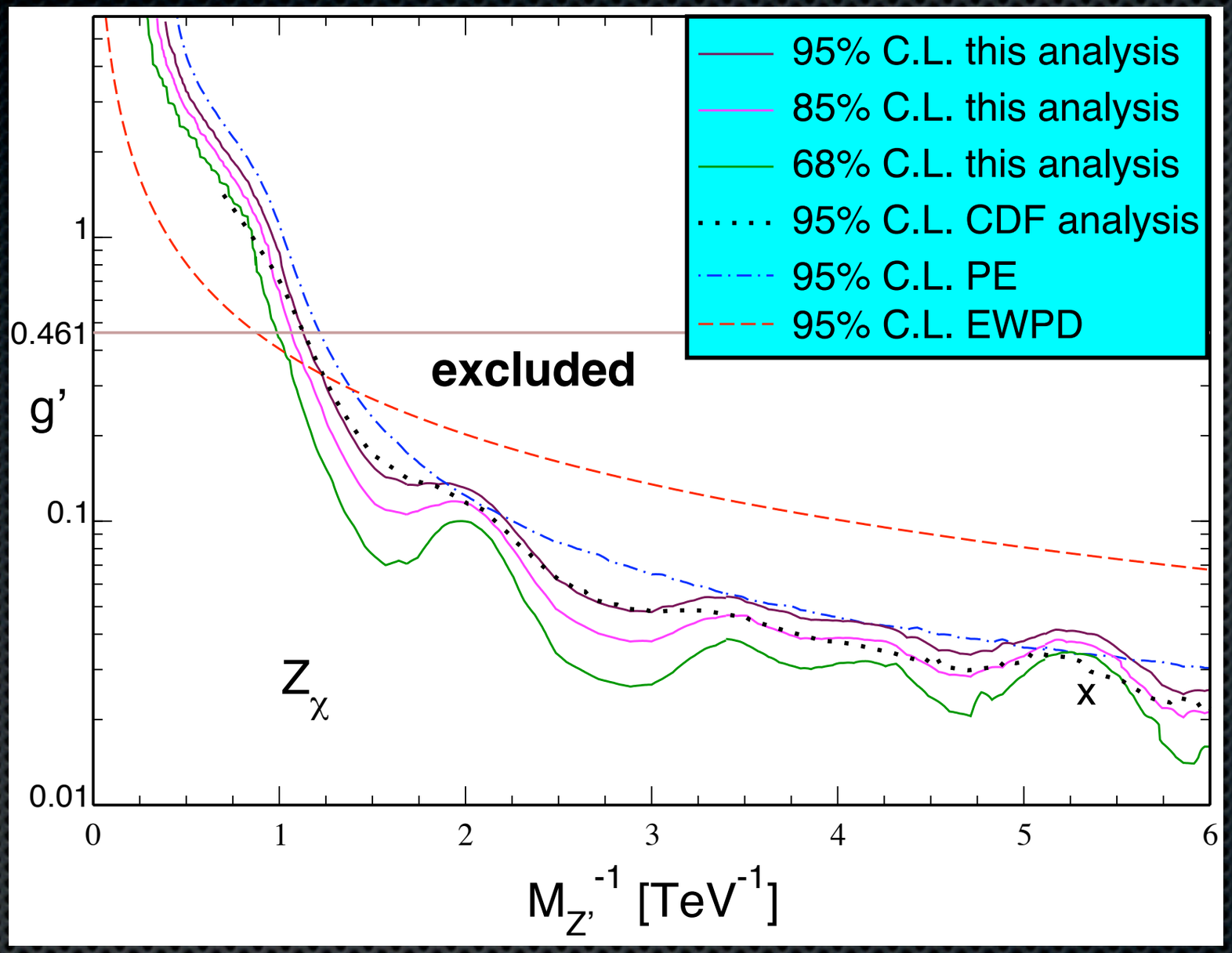
14



Interference effects

$Z_{u\text{-int}}^+ \approx -76°$, $\beta = 0$ (Z_ψ) maximizes constructive $\gamma Z'$ (destructive ZZ') interference for u-quarks

15



Comparative analysis of Z_χ

Complementarity of electroweak precision data and di-lepton channel analyses.

16

towards an integrated Z' analysis

17

towards an integrated Z' analysis

- next step: move from collection of mass limits to integrated analysis (especially after hint/discovery)

17

towards an integrated Z' analysis

- next step: move from collection of mass limits to integrated analysis (especially after hint/discovery)
- $p_{posterior}(M_{Z'}, g', \theta_{ZZ'}, \alpha, \beta) = p_{prior} \times \mathcal{L}_{EWPD} \times \prod_i \mathcal{L}_i$

17

towards an integrated Z' analysis

- next step: move from collection of mass limits to integrated analysis (especially after hint/discovery)
- $p_{posterior}(M_{Z'}, g', \theta_{ZZ'}, \alpha, \beta) = p_{prior} \times \mathcal{L}_{EWPD} \times \prod_i \mathcal{L}_i$
- combine LEP1, SLC, LEP2, Tevatron, LHC, CEBAF, table top, ... to disentangle parameters (lot of work)

17

towards an integrated Z' analysis

- next step: move from collection of mass limits to integrated analysis (especially after hint/discovery)
- $p_{posterior}(M_{Z'}, g', \theta_{ZZ'}, \alpha, \beta) = p_{prior} \times \mathcal{L}_{EWPD} \times \prod_i \mathcal{L}_i$
- combine LEP1, SLC, LEP2, Tevatron, LHC, CEBAF, table top, ... to disentangle parameters (lot of work)
- long-term project: suggests close collaboration between theorists (us) and experimentalists

17

Conclusions

18

Conclusions

- a TeV scale Z′ is a real possibility and its charges can give information on the underlying physics principles

18

Conclusions

- a TeV scale Z′ is a real possibility and its charges can give information on the underlying physics principles
- E_6 model class arises top-down and bottom-up (at least, as far as the known fermions are concerned)

18

Conclusions

- a TeV scale Z′ is a real possibility and its charges can give information on the underlying physics principles
- E_6 model class arises top-down and bottom-up (at least, as far as the known fermions are concerned)
- EWPD: give very tight constraints on $\theta_{ZZ'}$ and on $g'/M_{Z'}$

18

Conclusions

- a TeV scale Z′ is a real possibility and its charges can give information on the underlying physics principles
- E_6 model class arises top-down and bottom-up (at least, as far as the known fermions are concerned)
- EWPD: give very tight constraints on $\theta_{ZZ'}$ and on $g'/M_{Z'}$
- hadron colliders: complicated constraints in g′ vs. $M_{Z'}$

18

Conclusions

- a TeV scale Z′ is a real possibility and its charges can give information on the underlying physics principles
- E_6 model class arises top-down and bottom-up (at least, as far as the known fermions are concerned)
- EWPD: give very tight constraints on $\theta_{ZZ'}$ and on $g'/M_{Z'}$
- hadron colliders: complicated constraints in g′ vs. $M_{Z'}$
- closer collaboration between experimentalists and theorists warranted

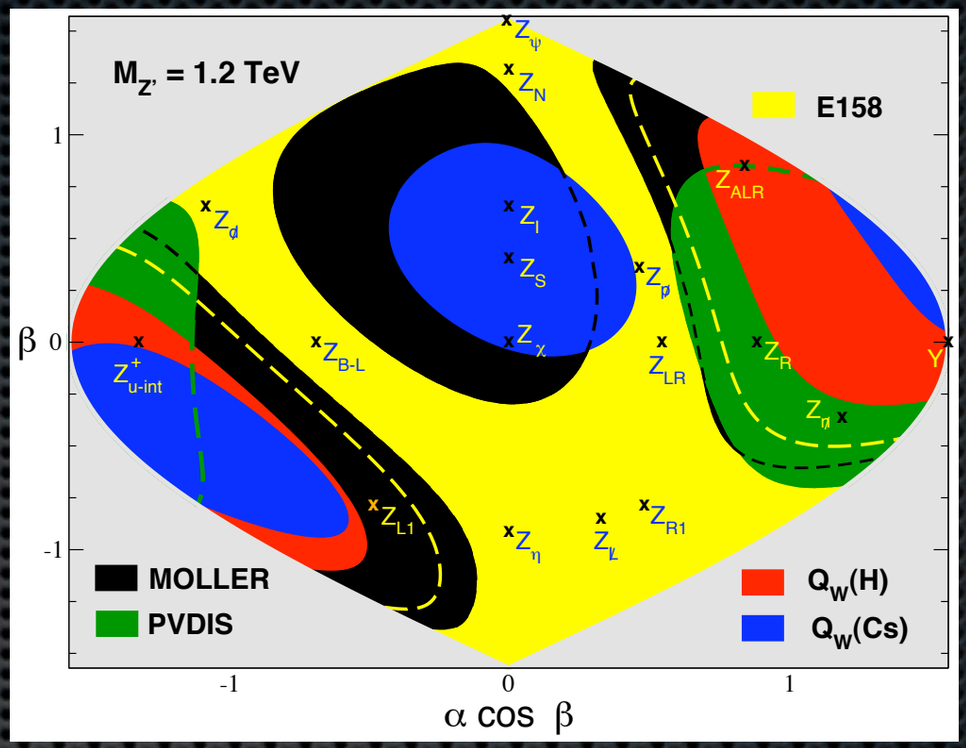
18

Z' bosons from E_6: collider and electroweak constraints (Jens Erler)

$\alpha = 0$: no kinetic mixing

$\beta = 0$: SO(10)

current & future



low energy constraints will exclude entire parameter space

this analysis: Bayesian style
CDF analysis: frequentist
EWPD: electroweak